"DEVELOPMENT OF A LOW-COST PACKAGE-BOMB CONTAINMENT VESSEL"

by

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ABSTRACT

Recently, the Naval Surface Warfare Center, Carderock Division (NSWC/CD) developed an affordable package-bomb containment vessel to protect personnel and equipment from the damaging effects of an explosion. The Explosive Containment Device (ECD) is a lightweight, plastically deforming pressure vessel designed to contain a single explosion at its full rated capacity. Integrating several original features into this singular loading containment vessel results in a device that is substantially lighter, and four to eight times cheaper than existing containment vessels. By confining the effects from unintentional activation of an Improvised Explosive Device (IED), the ECD offers law enforcement officials the benefits of safe transport using a bomb containment vessel without the associated cost and heavy weight of repetitive use fixtures. Addition of a fragmentation liner extends application of the ECD to encompass small fragmenting munitions such as pipe bombs, mortars, and grenades. Application for a patent covering the design of the ECD has been filed by the US Government under Navy Case Number 78,946.

BACKGROUND

The escalation of violence and militant activities against society compels responsible governing bodies to pursue physical security measures that limit exposure of the general populace to terrorist actions. The impact is especially apparent within international air travel. Airlines are beginning to expand the scope of luggage screening to include scanning stowed baggage for the presence of IEDs prior to loading into the aircraft cargo hold. However, if scanning identifies a suspected IED, security efforts must then shift to focus on preventing damage and injury. Two options exist, safe isolation of the suspect device within a bomb containment vessel or evacuation of the imperiled building.

Responding to this potential hazard, the Federal Aviation Administration (FAA) sought a suitable bomb containment vessel to complement their new CTX luggage screening equipment. The containment vessel that the FAA desired needed to confine blast and debris from an IED up to five lb. TNT. There were three significant design challenges. First, it should provide an access hatch sufficient to load either a large suitcase or a 20" x 20" x 42" shipping container. Next, capability for transit through a standard 36-inch door opening and on elevators was necessary. Finally, the bomb containment vessel should be light in weight and low in cost, preferably under 2000 lb. and $20,000 respectively.

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Although several competent bomb containment vessels were commercially available, none satisfied all of the FAA's functional requirements. Existing appliances were typically of imposing construction, which is by nature both costly and heavy. Their size and weight restricted conveyance within some buildings and elevators. Moreover, none could pass through a standard 36-inch doorway. Additionally, the small dimensions of the loading port on some designs restricted the size of items admitted into the containment vessel. Understandably, an IED concealed within baggage or a large package would require IED removal from the parcel before placing it in the containment vessel. That constituted an unacceptable level of handling and exposure hazard for the CTX technicians screening the baggage.

Upon determining that existing containment vessels would not meet operational requirements, the FAA turned to the Protection and Weapons Effects Department at NSWC/CD for assistance. Prior service to the FAA as a scientific advisor of weapon effects and structural response demonstrated NSWC/CD expertise in this area. NSWC/CD proposed that the best approach for a bomb containment vessel meeting FAA operational requirements would be the design of a plastically responding, single-use containment vessel. Allowing controlled inelastic response of the main structure fosters significant reductions in size, weight, and cost. While such a fixture could repeatedly transport suspected IEDs to safe sites for further evaluation and possible disarming, it would only withstand blast loading once at its full rated design capacity. Detonation of a stowed IED would expend the design life of the containment vessel.

Still, adopting a singular loading design philosophy is fully compatible with the tactical doctrines of most police bomb squads. Intentionally detonating an IED within a bomb containment vessel rarely if ever occurs. Rather, after safely transporting the suspect device to a remote location, technicians remove it from the bomb containment vessel and then attempt to disrupt it mechanically. Disrupting an IED rather than detonating it preserves more evidence for any subsequent forensic investigation. Furthermore, this procedure avoids the expense of inspecting and repairing the bomb containment vessel before returning it to service.

RATIONALE FOR AN INELASTIC DESIGN

Several compelling considerations motivated selecting an inelastic containment vessel approach. First, an inelastically responding pressure vessel allows designing for the space efficiency of a regular rectangular prismatic shell while still developing reasonable hoop stress once it has deformed into a rudimentary ovaloid. Hence, a containment vessel that passes through a 36-inch door opening need not constrain the maximum package size to that circumscribed by a 36-inch diameter sphere or cylinder. Second, dynamically loaded structures must not only resist the loading of interest, but also the mass inertia of the structure itself. An elastic structure, when dynamically loaded, may require up to twice the structural resistance of an equal magnitude load applied statically. By contrast, an inelastic structure uses the work performed during inelastic straining to dissipate the kinetic energy of the structure. This allows designing lighter structures for a given magnitude dynamic input. Finally, inelastic response of the shell provides a significant volume expansion. The attendant drop of the final equilibrium pressure further decreases the structural resistance required of the pressure vessel shell. Since NSWC/CD protection engineers had considerable experience with design of inelastic protective structure, choosing an inelastic pressure vessel allowed capitalizing on these advantages.

DESIGN PROCESS

Satisfactory performance of an inelastic, prismatic pressure vessel depends upon the ability of the shell to expand under blast loads into a rudimentary cylindrical or ovaloid pressure vessel. For the ECD, a pressure vessel shell that reliably achieves up to 10% average strain under the specified loading was the goal. Assuring high plastic-strain capacity under blast loading requires designing the shell from steel that offers high strength, ductility, and toughness. Proper weld-joint location, careful welding process control, and thorough non-destructive inspection also contribute to high plastic-strain capacity. Inhibiting shell rupture during deformation requires achieving reasonably uniform straining of the steel shell. Thus, preventing highly localized straining during either fabrication or blast loading is essential. Radial transitions at the intersections of the parallelogram faces and spherical transitions at each of the eight vertices prevent such highly localized strains. These radial or spherical transitions prevent strain concentrations that locally limit the remaining ductility of the steel and thus precipitate early rupture of the shell. True radial transitions that enter tangent to each face are necessary to prevent the high local strains that develop along discrete bends or creases. Naturally, metal forming operations must prevent introducing any highly localized strains at the intersection of adjacent shell panels. A continuous radius punch and die is one such method for properly forming these transitions in the shell plating. Machining the spherical transitions from steel bar stock accomplishes the same goal. Proper material selection and forming ensure adequate plastic strain capacity under service loads.

Design began by determining the necessary dimensions of the payload volume. Next, ballistic performance set a minimum shell thickness for the ECD. Although the design threat was not a cased munition, debris from the parcel would still accelerate to moderate velocities. The pressure vessel shell should confine this debris. Next, a rectangular prismatic envelope, uniformly spaced from the payload volume, established a baseline pressure vessel. This uniform spacing, if sufficient in magnitude, eliminates the chance for prompt impulsive rupture (shock holing) of the shell. NSWC/CD analyzed the baseline pressure shell by idealizing its panels as constant stress membranes. Inelastic deformation occurs once the stress level reaches the yield stress of the steel.

The access hatch to the ECD payload volume departs slightly from the rest of the pressure vessel shell in its design goal. While still inelastic in design, flexural rather than membrane response characterizes the structural behavior. A membrane access hatch is poorly suited to a containment vessel design that stresses operational speed, ease, and simplicity. Design of an attachment system that provided both quick operation and uniform load distribution around the door perimeter appeared infeasible. Conversely, a flexural response hatch lends itself to point application of loads and simple operation. The final hatch design employs box section stiffeners secured to a perimeter frame through rectangular shear pins. This attachment system develops almost 100% end fixity of the box section stiffeners, coupled with simplicity of design.

Although this light, high-strength steel shell would provide satisfactory performance for the global response, transit of the ECD through a 36-inch doorway dictated a proximate location for two shell panels of less than the desired separation. The shell would require either an increased thickness, or a decreased local loading. NSWC/CD chose to integrate both structural confinement and load attenuation into a single IED containment system to rectify this problem.

ENERGY OUTPUT FROM HIGH EXPLOSIVES

Let us temporarily consider the thermo-chemical progression of a typical High Explosive (HE) reaction in an air atmosphere. For purposes of discussion, we will resolve this complex reaction into two idealized phases, an initial phase that is anaerobic in nature, and an ensuing aerobic phase. The anaerobic phase involves the decomposition of the metastable explosive compound, various redox reactions involving the atomic species generated by decomposition of the original explosive compound, and a multitude of competing equilibrium reactions amongst the detonation products. All of the anaerobic phase, except for the various equilibrium reactions, occurs during passage of the detonation wave through the explosive compound. This idealized anaerobic phase involves only that mass of matter originally comprising the explosive charge.

During the subsequent aerobic phase, oxygen in the neighboring air promotes further oxidation of the detonation products. Typical military plastic explosives (usually the choice of terrorists) detonated in air liberate only a portion of their energy during the anaerobic phase. The remaining energy output occurs through oxidation of the detonation products during the aerobic phase. Turbulent mixing of the detonation products with the encompassing oxygen rich atmosphere is imperative for the aerobic phase to occur. Denial of access to ample oxygen impedes the aerobic phase of the reaction. Additionally, the aerobic phase is only self-sustaining when the energy released at the flame front exceeds the activation energy for the succeeding reaction cell. Any influence that drops the available energy at the flame front below this activation energy will quench the reaction. Naturally, any impediment to completion of the aerobic phase diminishes the specific energy output for the HE.

It is readily apparent that the total energy output of a HE reaction in air is not invariant. While it is usually reasonable to assume maximum yield (complete oxidation) for detonation of HE in free air, this frequently does not remain true for detonation of HE in confined volumes. For a confined detonation, the total energy output depends upon the quantity of supplementary atmospheric oxygen available, the degree of mixing between the detonation products and the oxygen, and success in propagating the after-burn flame front. Sufficient reduction of any of these parameters can cause a drop in the final energy yield for the HE.

REDUCTION OF STRUCTURAL LOADING

Certain features within the ECD design reduce the overall load experienced by the pressure vessel shell. These permit use of a lighter steel shell for the ECD. A foam core in the ECD diminishes the energy released by detonation of an explosive charge by limiting the free oxygen in the immediate vicinity of the explosive charge. A preferred implementation of the ECD sizes the central cavity only large enough to accommodate a suspect parcel. The remaining volume inside the ECD is filled with rigid foam or foam planks. With little atmospheric oxygen in the vessel, the aerobic phase is incomplete and virtually non-existent. This reduces the total energy output of the bomb, and thus diminishes the damaging effects of an internal munition reaction.

A second mechanism that reduces the overall load experienced by the pressure vessel shell is shock attenuation. The rigid foam liner attenuates the expanding shock front via, the

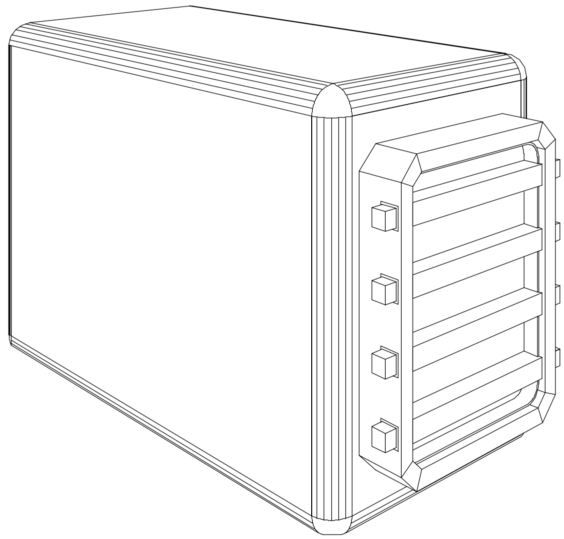
mechanical work expended during crushing of the foam, destructive interactions among shock reflections off various particle surfaces within the foam, and increasing of internal energy of the foam during transit of the shock wave. Additionally, the foam core constrains the minimum distance from the IED to the shell wall. Coupled with the shock attenuating effect, this prevents local shock loading from causing prompt impulsive rupture (shock holing) of the pressure vessel shell.

A final mechanism that reduces the overall load experienced by the pressure vessel shell is a drop in confined gas pressure caused by transfer of thermal energy to the pulverized foam particles. These foam particles act as heat sinks, substantially dropping the temperature of the gaseous detonation products. This large drop of gas temperature causes an attendant drop in gas pressure. This rapid heat transfer owes to the tremendous surface area created during pulverization of the foam core of the ECD. This heat transfer occurs in as little as 1 – 2 milliseconds. One key to successful implementation of this phenomenon is use of frangible rigid foam.

In summary, the mechanics of reducing the load on the pressure vessel shell are fourfold. First, the foam physically alters the reaction process by eliminating free atmospheric oxygen and thereby reduces the total energy liberated during the reaction. Secondly, the foam attenuates shock. Thirdly, the foam core physically limits the proximate location of the bomb to a safe distance from the shell wall. Finally, the pulverized foam functions as a thermal accumulator (heat sink). Thermal energy transferred to the heat sink decreases the temperature and thus the pressure of the aggregate gasses in the reaction volume. Diminished structural loading on the pressure vessel shell is possible because all of these mechanisms occur on a time scale shorter than or comparable to the response time of the shell. The result of proper load attenuating techniques is adequate pressure vessel performance from a thinner shell than otherwise possible.

DESCRIPTION OF THE ECD

The ECD was the outcome of this design process. Weighing approximately 1500 lb., this containment system measures 78 inches long, 48 inches high, and 34 inches wide. A thin, high-strength, rectangular prismatic steel shell filled with rigid polyurethane foam provides the basis for this design. A large rectangular access hatch at one end of the shell opens into a polyethylene-lined payload cavity within the foam. Measuring 21 inches wide by 30 inches high, this access hatch admits the entire suspect device or package into the payload cavity of the ECD. After introducing the suspect device and closing the access hatch, eight steel shear pins secure the hatch against opening under blast loads. A simple lip-seal around the hatch perimeter controls ejection of particulate matter from the ECD. This seal also controls bleed-down to ambient pressures over 10-20 seconds. Projected cost for an ECD is under $20,000.



OPERATION OF THE ECD

1. Remove the eight steel dogging pins and swing open the door.
2. Remove all packing materials (Foam Billet and Foam Planks) from the ECD's payload cavity.
3. Place the suspect parcel within the ECD's payload cavity and slide it to the rear of the bore.
4. Install foam planks (provided) loosely on both sides of the package to reduce free atmospheric air in the ECD and prevent package shifting during transit.
5. Slip the large foam billet (also provided) into the bore to isolate the IED from the door assembly.
6. Swing the door shut, then slide the eight dogging pins into engagement with the door stiffeners until they contact the pin stops inside the door.
7. Finally, clip the dogging pin lanyard clasps to the attachment loops on the doorframe to prevent disengagement of the dogging pins during transport.

NOTE: Staging the ECD with the door unsecured and the central cavity empty speeds operation and is the preferred implementation.

CONCLUSION

The ECD is a thin, high-strength, rectangular prismatic steel shell filled with rigid polyurethane foam. Selecting a rectangular shape offers space efficiency, while controlled inelastic response permits lighter weight, similar to a cylinder. An efficient size allows moving the ECD within a building rather than having a bomb retrieval robot move the IED from the building to a containment vessel. Furthermore, low cost allows dedicated siting of an ECD with each airport CTX scanning system. On 31 January 1997, the first prototype successfully passed testing by 5 lb. of C-4, a loading of greater than design severity. The first ECD to enter service arrived at Hartsfield, Atlanta, Georgia on 14 April 1997. An application for a patent covering the design of the ECD has also been filed by the US Government under Navy Case Number 78,946.